Docket No.: 1509-4[illegible] **PATENT**

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	:	
	:	
David SIKHARULIDZE	:	
	:	
U.S. Patent Application No. 10/698,028	:	Group Art Unit: 1772
	:	
Filed: October 31, 2003	:	

For: BISTABLE NEMATIC LIQUID CRYSTAL DISPLAY DEVICE

TRANSMITTAL OF CERTIFIED PRIORITY DOCUMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

At the time the above application was filed, priority was claimed based on the following applications:

British Application No. 0225405.0, filed October 31, 2002.

A copy of the priority application is enclosed.

Respectfully submitted,

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AML/gmj

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

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Dated 30 October 2003

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Request for grant of a patent

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1.	Your reference	300111171-1 GB
2.	Patent application number *(The Patent Office will fill in this part)*	0225405.0 31 OCT 2002
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Hewlett-Packard Company 3000 Hanover Street Palo Alto CA 94304, USA
	Patents ADP number *(if you know it)*	4965880001
	If the applicant is a corporate body, give the country/state of its incorporation	Delaware, USA
4.	Title of the invention	Bistable Nematic Liquid Crystal Display Device
5.	Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Richard A. Lawrence Hewlett-Packard Ltd, IP Section Filton Road, Stoke Gifford Bristol BS34 8QZ
	Patents ADP number *(if you know it)*	744863800l
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country / Priority application number *(if you know it)* / Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application / Date of filing *(day / month / year)*
8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	Yes

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	23
Claim(s)	5
Abstract	1
Drawing(s)	~~7~~ 7

10. If you are also filing any of the following, state how many against each item.

Priority documents	-
Translations of priority documents	-
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	1
Request for preliminary examination and search *(Patents Form 9/77)*	2 ~~1~~
Request for substantive examination *(Patents Form 10/77)*	-
Any other documents *(please specify)*	Fee Sheet

11. I/We request the grant of a patent on the basis of this application.

Signature Richard A. Lawrence

Date 31/10/02

12. Name and daytime telephone number of person to contact in the United Kingdom

Meg Joyce Tel: 0117-312-9068

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BISTABLE NEMATIC LIQUID CRYSTAL DISPLAY DEVICE

FIELD OF THE INVENTION

This invention relates to bistable nematic liquid crystal display devices.

BACKGROUND OF THE INVENTION

Pixel bistability is a desirable attribute for a liquid crystal display ("LCD") because this eliminates the need constantly to refresh the display or to employ a silicon memory device behind each pixel, which becomes prohibitively expensive as the number of pixels increases. With bistability, only pixels that need to be changed need addressing, and simple matrix addressing may be employed.

Bistable LCDs are known which employ chiral tilted smectic liquid crystals, for example chiral smectic C materials, which exhibit ferroelectricity. However, there are many problems with ferroelectric LCDs, including a paucity of stable, room-temperature materials, wide-temperature-range materials, and structural defects which result from mechanical stress. Because of the problems associated with ferroelectric smectic materials it is desirable to fabricate bistable LCDs using nematic liquid crystals ("LCs").

US patent number 4,333,708 discloses a multistable nematic LC device in which switching between stable configurations is by the movement of disclinations in response to electric fields.

In WO 91/11747 and WO 92/00546 it is proposed to provide a bistable surface by careful control of the thickness and evaporation of SiO coatings. A first stable planar orientation of the director could be obtained, and a second stable orientation in which the director is at an azimuthal angle (in the plane of the surface) of 90° to the first orientation in the plane of the surface, and tilted by around 30°.

In "Mechanically Bistable Liquid-Crystal Display Structures", R N Thurston et al, IEEE Trans. on Elec. Devices, Vol. ED-27, No. 11, Nov. 1980, there are described two bistable nematic LC modes which are called "vertical-horizontal" and "horizontal-horizontal". In the vertical-horizontal mode, both cell walls are treated to give a roughly 45° tilt which permits the directors to be switched between two states in a plane which is perpendicular to the major surfaces of the device. In the horizontal-horizontal mode, the director is switchable between two angles in a plane parallel to the major surfaces of the device.

A bistable nematic display using monostable surface switching has been proposed by I. Dozov *et al*, *Appl. Phys. Lett.* 70 (9), 1179, 3 March 1997. Switching in a thin

as lecithin. This grating surface is used to form a Zenithal Bistable Device or ZBD.

A bistable nematic device was described EP 1 139 151, wherein one cell wall is provided with an array of upstanding features which have a shape and/or orientation to induce the local director to adopt two different tilt angles in substantially the same azimuthal direction. The arrangement is such that two stable molecular configurations can exist after suitable electrical signals have been applied. The features are typically microscopic posts, used to form a Post-Aligned Bistable Nematic device, or PABN.

Typically the depth of gratings or post alignment features of the ZBD or PABN devices is about 1 μm and the ratio depth/width is about 0.6. Gratings this deep are fairly challenging to replicate by mass manufacturing methods.

Bistable nematic displays have been described in which the nematic LC has dispersed in it nanoparticles which are believed to form structures that stabilise the LC in either a scattering state or a homeotropic (non-scattering) state. Switching between the states is achieved either by two-frequency addressing or by the action of a laser. Two frequency-addressable displays are described in: R. Eidenschink, W. H. De Jue "Static scattering in filled nematic: new liquid crystal display technique" *Electronics Letters* 20 June 1991, vol. 27, No. 13, pp 1195-1196, A. Gluschenko *et al* "Memory effect in

at least one electrode on each cell wall for applying an electric field across at least some of the liquid crystal material;

a first surface alignment on the inner surface of one cell wall for inducing adjacent molecules of the liquid crystal material to adopt a first orientation, and a second surface alignment on the inner surface of the other cell wall for inducing adjacent molecules of the liquid crystal material to adopt a second orientation which is different from the first orientation;

whereby the nematic liquid crystal material will adopt a first stable molecular configuration in response to a pulse of a unidirectional electric field of suitable magnitude and duration via the electrodes and will adopt a second stable molecular configuration in response to a similar pulse of opposite polarity, the second configuration being different from the first configuration.

The invention provides polarity-controlled switching because of the nature of the interactions between the dispersed particles and the LC molecules and so may be applied to LC cells with a range of alignment configurations.

The dispersed particles preferably have a size in the range 1 nm to 1000 nm, particularly 5 to 50 nm. Suitable particles will be referred to herein as nanoparticles. The nanoparticles may be spherical or spheroidal. The nanoparticles are preferably present in a concentration of

drive electronics connected to the electrodes, for applying pulses of DC electric fields of desired magnitude, polarity and duration, whereby the liquid crystal material will adopt two different stable molecular configurations according to the polarity of the applied field.

Without limiting the invention in any way, we believe that the particles are or become charged by contact with the LC material, and that the display operates by an electrophoretic effect whereby charged particles migrate and aggregate at the cell wall electrode of opposite sign, thereby screening the LC material from the effects of the surface alignment on that wall. Evidence for this mechanism will be discussed in the detailed description.

Accordingly, a further aspect of the present invention provides an electrophoretically controlled bistable liquid crystal display device comprising:

a first cell wall and a second cell wall enclosing a layer of nematic liquid crystal material, at least one of the cell walls being translucent;

the liquid crystal material having finely divided charged particles dispersed therein;

at least one electrode on each cell wall for applying an electric field across at least some of the liquid crystal material; and

a first surface alignment on the inner surface of the first cell wall for inducing adjacent molecules of the liquid crystal material to adopt a first orientation, and

alignments with the planar direction determined by one or other of the surface alignments. The switching of these display modes will be described in more detail below.

The invention will now be further described, by way of example only, with reference to the following drawings.

DETAILED DESCRIPTION

Figure 1 shows a homeoplanar (HAN) cell comprising first and second opposed substrates (cell walls) 1 each of which carries transparent electrodes 2. One substrate of this cell is provided with a homeotropic surface alignment 3, which provides vertical alignment of molecules close to surface. The other substrate is provided with a planar alignment 4 which provides parallel alignment to molecules close to that surface. The cell was filled with a mixture 5 of nematic LC with silica nanoparticles dispersed therein. Between crossed polarizers the cell's transmission is described by:

$$I_{out} = I_0 \sin^2 2\alpha \sin^2 (2\pi d\ \Delta n / \lambda).$$

where I_0 = input light, α = angle between input polarizer and director (orientation of LC molecules), d = cell thickness, Δn = optical anisotropy , λ = light wavelength.

Figure 2 shows the cell's transmission under applied electrical pulses between crossed polarizers (α= 45° with respect to LC director). The cell studied contained dyed nematic (ZLI3572 from Merck) and 2% silica nanoparticles (Aerosil® R974 from Degussa-Huls). The nanoparticles have an average primary particle size of 12 nm. They comprise fumed silica aftertreated with dimethyldichlorosilane. The SiO_2 content of the nanoparticles is >99.8%. The cell thickness was 10 μm. 15 ms 30 V pulses were applied. We found that depending on the polarity of the applied pulses the cell behaves differently. When the positive sign is

display to a memorized homeotropic state, and positive polarity on the planar side induces switching back to the initial surface aligned state. In Figure 4b, connecting the positive sign to the planar side switches the display to a memorized homeotropic state, and negative polarity on the planar side induces switching back to the initial surface aligned state. The cells thus show opposite switching behaviour depending on polarity.

Referring now to Figure 5, electro-optical switching to the memorized state is shown for a nematic HAN cell filled with silica (E7 and 2% R812). The cell thickness was 10 μm; pulse length was 5 ms. A higher voltage is required to switch to the memorized state than the voltage for the homeotropic reorientation.

Figure 6 a,b represents the evolution of electro-optical response of the cell with applied bursts of unidirectional electric field pulses of increasing amplitude: 0, 18.6 V, 36.8 V, 55.2 V, 73.6 V, 92 V. (Figure 6 correlates with Figure 5 and shows that although switching to the homeotropic state is observed for a pulse with 18 V, the memorized effect requires a pulse with 55 V for a cell with thickness 10 μm.). It should be noted that the cell continues to be capable of bistable switching with increasing temperature. The comparison of the switching shows that there is not much difference between memorized effects at room temperature and at 60°C. Only the back switching is faster, because of reduction of the viscosity γ at higher temperature. These results suggest that the

observed polarity controlled effect is distinct from known devices in which a memory effect is based on the creation of a network of nanoparticles along the cell, and back switching is provided only by thermal heating of the cell (US Patent No. 5,532,952, and M. Kreuzer *et al* "New liquid crystal display with bistability and selective erasure using scattering in filled nematics" *Appl. Phys. Lett.*, 62(15), 12 April 1993, pp 1712-1714)

We believe that the invention provides a different mechanism of bistable switching - electrophoretically controlled bistability in LCDs. According to this mechanism, the electrophoretric effect, which takes place in the cell, is responsible for the memorized effect. This was tested in a cell with in-plane electrodes 2, as shown in Figure 7. The mixture of LC with nanoparticles 5 was deposited over a bottom substrate 1a and covered the area between the electrodes. A thin (100 μm) glass plate 1b covered the LC layer. The cell was observed by polarizing microscopy. Electrical pulses with reversed polarity were applied to the electrodes 2. In Figures 7 a,b are given pictures of the switching process between in-plane electrodes for liquid crystal E7 doped with 2% OX50 silica(40 nm). In the texture of the mixture is observed quite big size clusters, which are formed by aggregation and enables the observation of the migration process. In the beginning the aggregates are randomly distributed in the LC. After application of the pulse the aggregates begin the moving towards the electrode with suitable polarity, in this case towards the electrode with a plus

sign. Depending on amplitude and duration of pulse they are fully collected close to the electrode, forming a close-packed network of the nanoparticles. This state is stable after switching off the electrical pulse. After reversing polarity the aggregates are moved and collected close to the second electrode, and the area close to the first electrode is cleaned of close-packed nanoparticles networks. The same behaviour takes place for a mixture with smaller size (7 nm) nanoparticles. In this case the network of the nanoparticles is observed as a dense layer, which moves between in-plane electrodes. The mobility of nanoparticles was determined from the expression for drifting under an electrical field $t_{dr}= d^2/ \mu V$, where d is the distance between electrodes, V = applied voltage, μ = mobility. The distance between electrodes is 100 μm and there is optically observed that the pulse 100 ms with amplitude 200 V forces full drifting of the nanoparticles from one electrode to the second electrode. Consequently we have determined the mobility $\mu = d^2/ t_i V= 10^{-4}cm^2/ 10^{-1}s$ $2.10^2 V= 5.10^{-6} cm^2/ Vs$, which is a typical value for mobility of solid nanoparticles in liquids.

Accordingly in the cell with thickness 10 μm and applied voltage 50 V, the duration of the pulse which provides a bistable switching will be equal to $t_{dr}= d^2/ \mu V= 10^{-6} cm^2/$ $(5\ 10^{-6} cm^2/Vs)$ 50 V= 4 ms. The comparison of this value with Figure 8 shows a good coincidence, that provides supporting evidence for the electrophoretic nature of the memorized effect.

determined by the liquid crystal layer as in conventional nematic cells. At the same time the stimulated switching and stabilisation of the switched states are controlled by the nanoparticles' optically "hidden" electrophoretic effect. Taking into account that this effect dramatically changes and stabilizes alignment close to the surface with the suitable sign of the polarity, it is very important to choose the LC cell's aligned configuration which enables the memorized state to be optically clearly distinguished from the previous state.

In the present invention the switching on and switching off processes need equal values of amplitude/duration with opposite polarity of electrical pulses, as shown in Figure 8., because of the electrophoretic mechanism of the controlling process. Figure 8 shows the threshold of switching to the memorized state and back switching depending on pulse duration; they are linked according to the expression $t_{dr}= d^2/ \mu V$. The results are for a 10 μm HAN cell filled with dyed nematic (ZLI3572) with 5% silica (Aerosil® R974).

The surface localized effect is also confirmed by investigation of an antiparallel cell, having both sides covered by polyimide layers for planar alignment. The cell was filled with E7 nematic LC with 2% Aerosil® R812 silica. The cell was not glued, to enable examination of the open surfaces after application of a voltage. The silica has a tendency to acquire negative charge, which promotes transition to the homeotropic state when positive

polarity is applied to the planar surface. The examination of the open surfaces between crossed polarizers shows that the surface to which was applied the plus sign of electrical pulse has homeotropic vertical alignment of molecules (Figure 9a), and the opposite surface has horizontal planar alignment (Figure 9b). After reassembling of the cell and reversing of the polarity the examination of the open surfaces shows the opposite effect: the surface which had vertical alignment, has now got planar alignment (Figure 10a) and the surface which previously exhibited planar alignment now exhibits homeotropic alignment (Figure 10b). These states are very stable and remain even after heating to the isotropic phase and cooling (Figure 11 a,b).

The bistability of the present invention is based on the nature of interaction of nanoparticles with LC molecules and so may be applied to LC cells with different configurations and compositions. The effect is very stable and works in cells with different thicknesses and various different alignment arrangements. We have investigated cells with the following different configurations: homeoplanar, twisted, antiparallel, homeotropic with thickness varied between 1 - 50 μm. For planar alignment were used rubbed polyimide layers, photoaligned LPP layers and photolithographically-made grating surface. As liquid crystals have been used commercial materials: with positive dielectric anisotropy E7, ZLI2293, MLC6693, ZLI4792,dyed (blue) nematic ZLI3572, (black) ZLI4727, ZLI4714/3, ZLI4756/2, with negative dielectric anisotropy

homeoplanar state and non-coloured transparent vertical state. Figure 12 shows a stable dyed nematic cell formed using plastic 2x2 inch^2 cell walls. The cell has homeoplanar geometry: one substrate was treated to give homeotropic orientation and the other was treated with rubbed polyimide for the planar alignment. The cell thickness was 10 μm, set by polymer beads sprayed between the plastic substrates. The cell was filled with dyed blue nematic LC ZLI3572 doped with 2% silica (Aerosil® R974).

It is appreciated that certain features of the invention, which are for clarity described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention which are, for the sake of brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination.

3. A device as claimed in any preceding claim, wherein the particles are capable of acquiring charge in suspension in a liquid crystal material.

4. A device as claimed in any preceding claim, further including drive electronics for applying unidirectional electric field pulses to the electrodes.

5. A bistable liquid crystal display device comprising:

two cell walls enclosing a layer of nematic liquid crystal material having finely divided solid particles dispersed therein, at least one of the cell walls being translucent;

at least one electrode on each cell wall for applying an electric field across at least some of the liquid crystal material;

a first surface alignment on the inner surface of one cell wall for inducing adjacent molecules of the liquid crystal material to adopt a first desired orientation;

a second surface alignment on the inner surface of the other cell wall for inducing adjacent molecules of the liquid crystal material to adopt a second desired orientation; and

drive electronics connected to the electrodes, for applying pulses of DC electric fields of desired magnitude, polarity and duration, whereby the liquid crystal material will adopt two different stable molecular configurations according to the polarity of the applied field.

6. A device as claimed in claim 5, wherein the said first desired orientation is different from the said second desired orientation.

7. An electrophoretically controlled bistable liquid crystal display device comprising:

a first cell wall and a second cell wall enclosing a layer of nematic liquid crystal material, at least one of the cell walls being translucent;

the liquid crystal material having finely divided charged particles dispersed therein;

at least one electrode on each cell wall for applying an electric field across at least some of the liquid crystal material; and

a first surface alignment on the inner surface of the first cell wall for inducing adjacent molecules of the liquid crystal material to adopt a first orientation, and a second surface alignment on the inner surface of the second cell wall for inducing adjacent molecules of the liquid crystal material to adopt a second orientation which is different from the first orientation;

whereby the liquid crystal material may be switched to a first stable molecular configuration by the application of a DC electric field pulse of suitable field strength and duration to cause movement of charged particles to the first cell wall so as substantially to prevent the first surface alignment from influencing alignment of molecules of liquid crystal material in the layer; and

the liquid crystal material may be switched from the first configuration to a second stable molecular configuration by the application of a DC electric field pulse of suitable field strength and duration and opposite polarity so as to cause movement of sufficient charged particles away from the first cell wall to permit the first surface alignment to influence alignment of molecules of liquid crystal material in the layer.

8. A device as claimed in any preceding claim, wherein the particles have a size in the range 1 to 1000 nm.

9. A device as claimed in any preceding claim, wherein the particles have a size in the range 5 to 50 nm.

10. A device as claimed in any preceding claim, wherein the first surface alignment induces planar alignment and the second surface alignment induces homeotropic alignment.

11. A device as claimed in any of claims 1 to 9, wherein both surface alignments induce planar alignment at substantially 90° to each other.

12. A device as claimed in any preceding claim, wherein the particles comprise at least one material selected from the group comprising silica, alumina, clay, and titanium dioxide.

13. A device as claimed in any preceding claim, wherein the particles are silica particles.

14. A device as claimed in any preceding claim, wherein the particles are present in a concentration of from 0.1% to 25% by weight of the liquid crystal.

15. A device as claimed in claim 14, wherein the particles are present in a concentration of from 1 to 15% by weight of the liquid crystal.

16. A device as claimed in claim 14, wherein the particles are present in a concentration of from 1 to 5% by weight of the liquid crystal.

17. A device as claimed in any preceding claim, wherein the liquid crystal has a pleochroic dye dissolved therein.

ABSTRACT

BISTABLE NEMATIC LIQUID CRYSTAL DISPLAY DEVICE

A bistable nematic liquid crystal display device comprises two cell walls (1) enclosing a layer of nematic liquid crystal material (5) having finely divided solid particles dispersed therein. At least one electrode (2) is provided on each cell wall (1) for applying an electric field across at least some of the liquid crystal material (5), and surface alignments (3, 4) are provided on the inner surface of both cell walls (1) for inducing adjacent molecules of the liquid crystal material (5) to adopt desired orientations. The liquid crystal material (5) will adopt two different stable molecular configurations according to the polarity of applied electric field pulses.

Figure 1

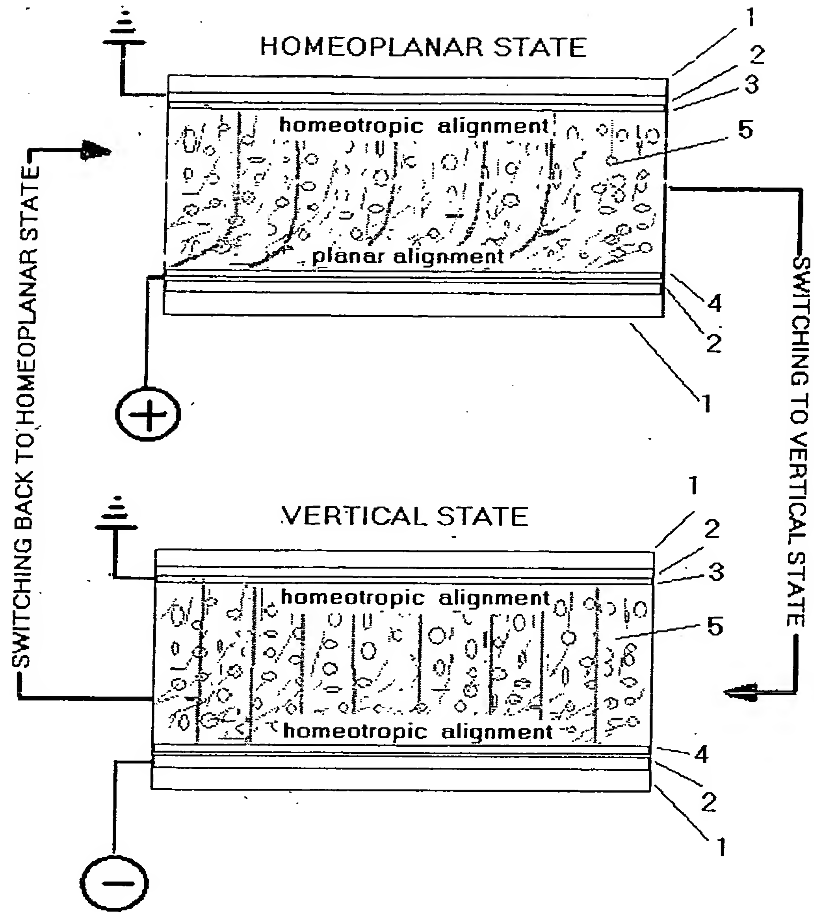

HOMEOPLANAR STATE
homeotropic alignment
planar alignment
VERTICAL STATE
homeotropic alignment
homeotropic alignment
SWITCHING BACK TO HOMEOPLANAR STATE
SWITCHING TO VERTICAL STATE
1
2
3
4
5
+
−

FIG. 1

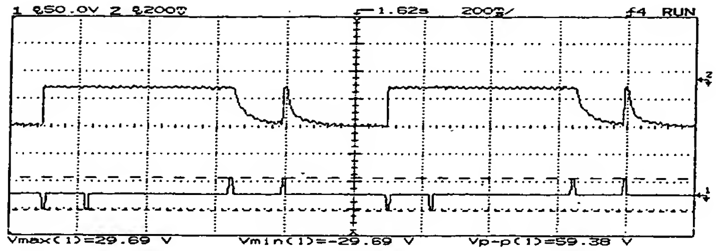


FIG. 2

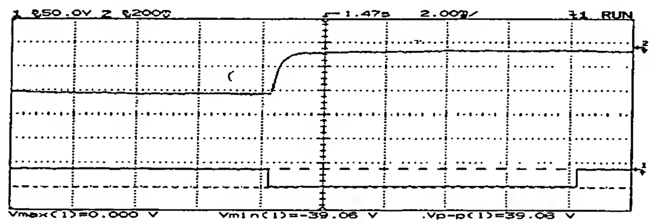


FIG.3a

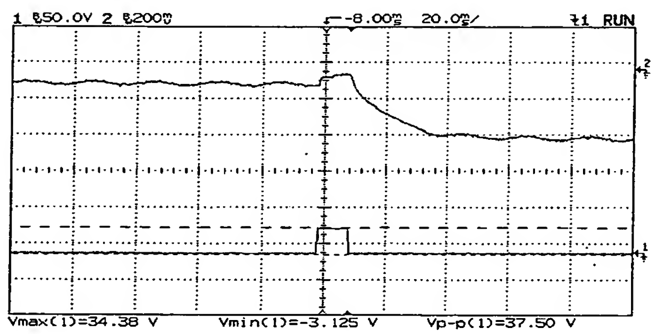
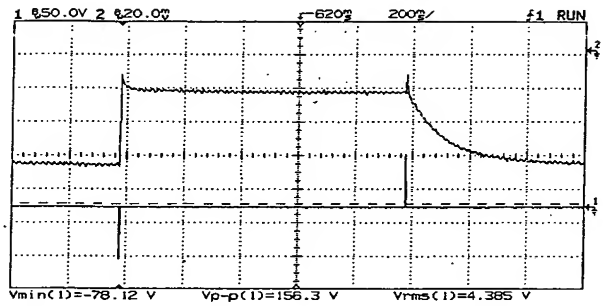


FIG. 3b


1 50.0V 2 20.0
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f1 RUN
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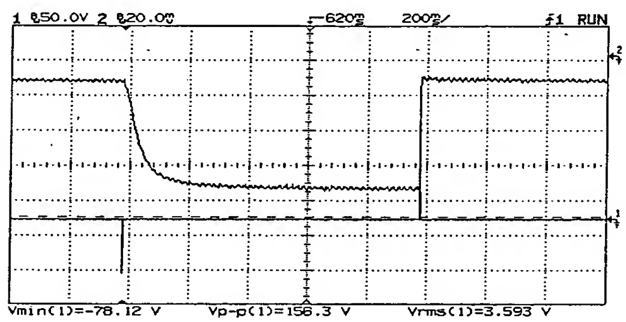
Vp-p(1)=156.3 V
Vrms(1)=4.385 V

FIG. 4a


1 50.0V 2 20.0
-620
200/
f1 RUN
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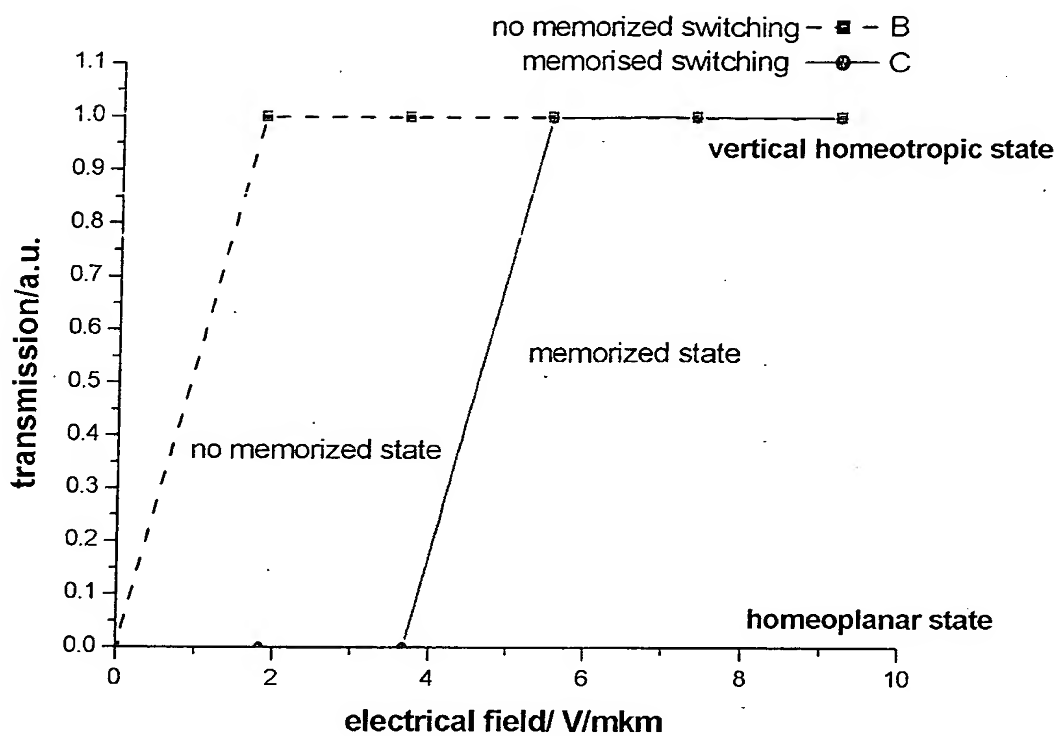
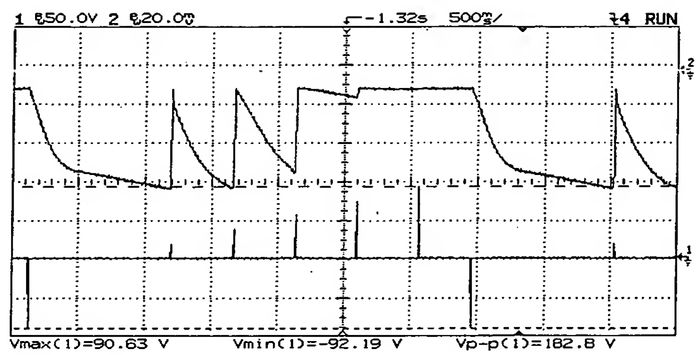
Vp-p(1)=156.3 V
Vrms(1)=3.593 V

FIG. 4b



no memorized switching – ■ – B
memorised switching —⊕— C
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
transmission/a.u.
vertical homeotropic state
memorized state
no memorized state
homeoplanar state
0
2
4
6
8
10
electrical field/ V/mkm

FIG. 5


1 50.0V 2 20.0
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4 RUN
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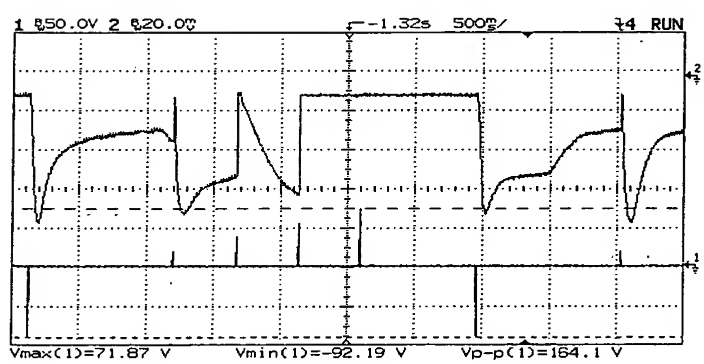
Vmin(1)=-92.19 V
Vp-p(1)=182.8 V

FIG. 6a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4 RUN
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Vmin(1)=-92.19 V
Vp-p(1)=164.1 V

FIG. 6b

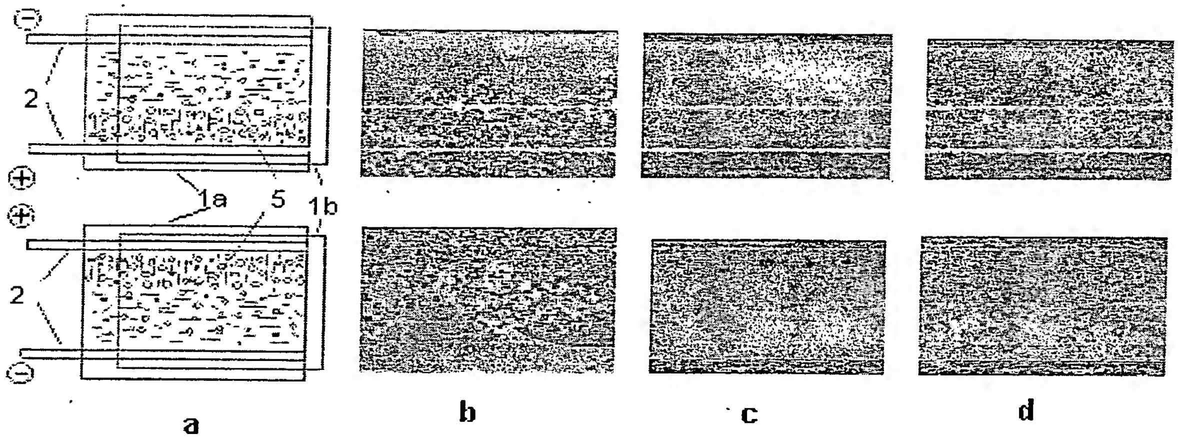
2
1a
5
1b
2
a
b
c
d

FIG. 7

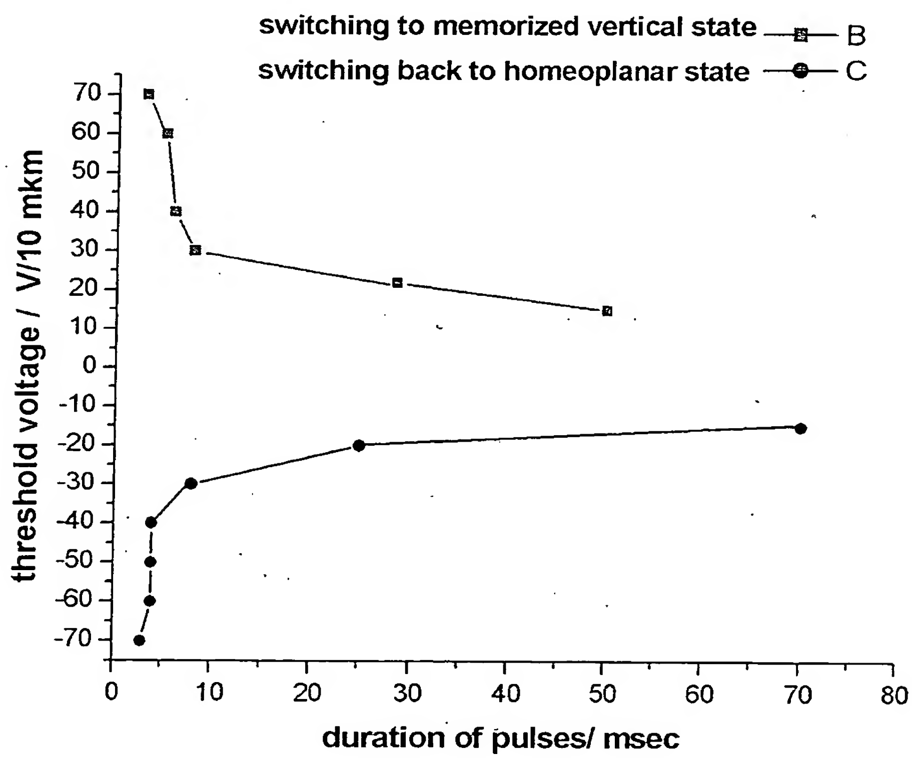
switching to memorized vertical state B
switching back to homeoplanar state C
threshold voltage / V/10 mkm
duration of pulses/ msec
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
0
10
20
30
40
50
60
70
80

FIG. 8.

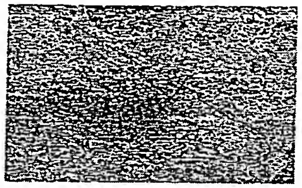

FIG. 9a

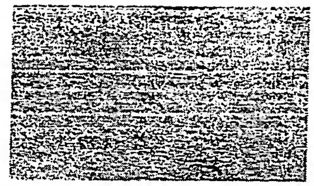

FIG. 9b

FIG. 10a

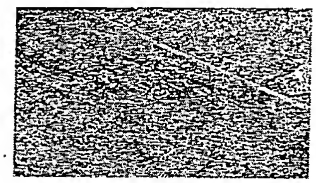

FIG. 10b

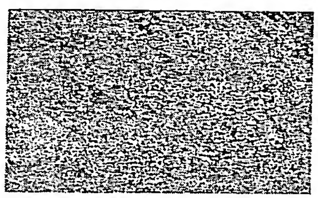

FIG. 11a

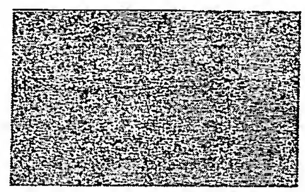

FIG. 11b

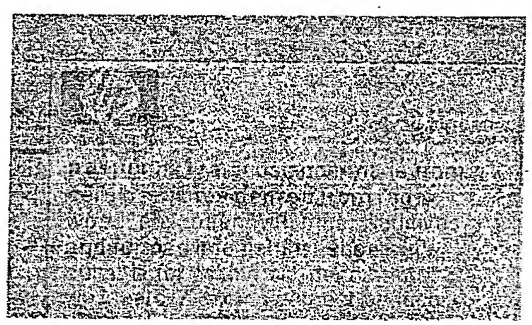

FIG. 12